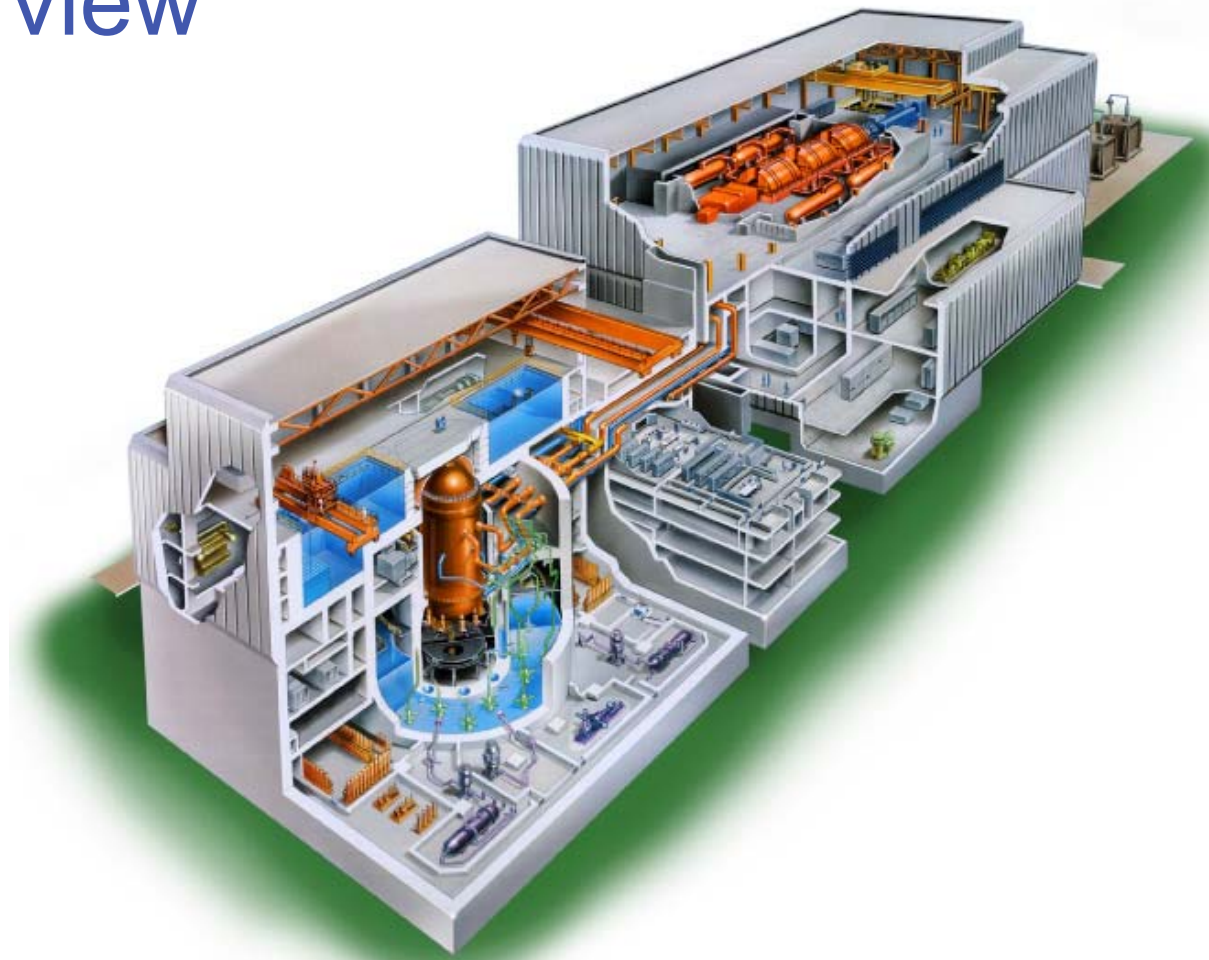


ABWR Overview



J. Alan Beard
April 13, 2007

Outline

- BWR Overview
- Containment
- Nuclear Steam Supply
- Engineered Safety Features
- Digital C&I (separate presentation)
- Miscellaneous Systems (separate presentation)
- Safety (Core Damage) (separate presentation)
- Defense in Depth (Severe Accidents) (separate presentation)

BWR Overview

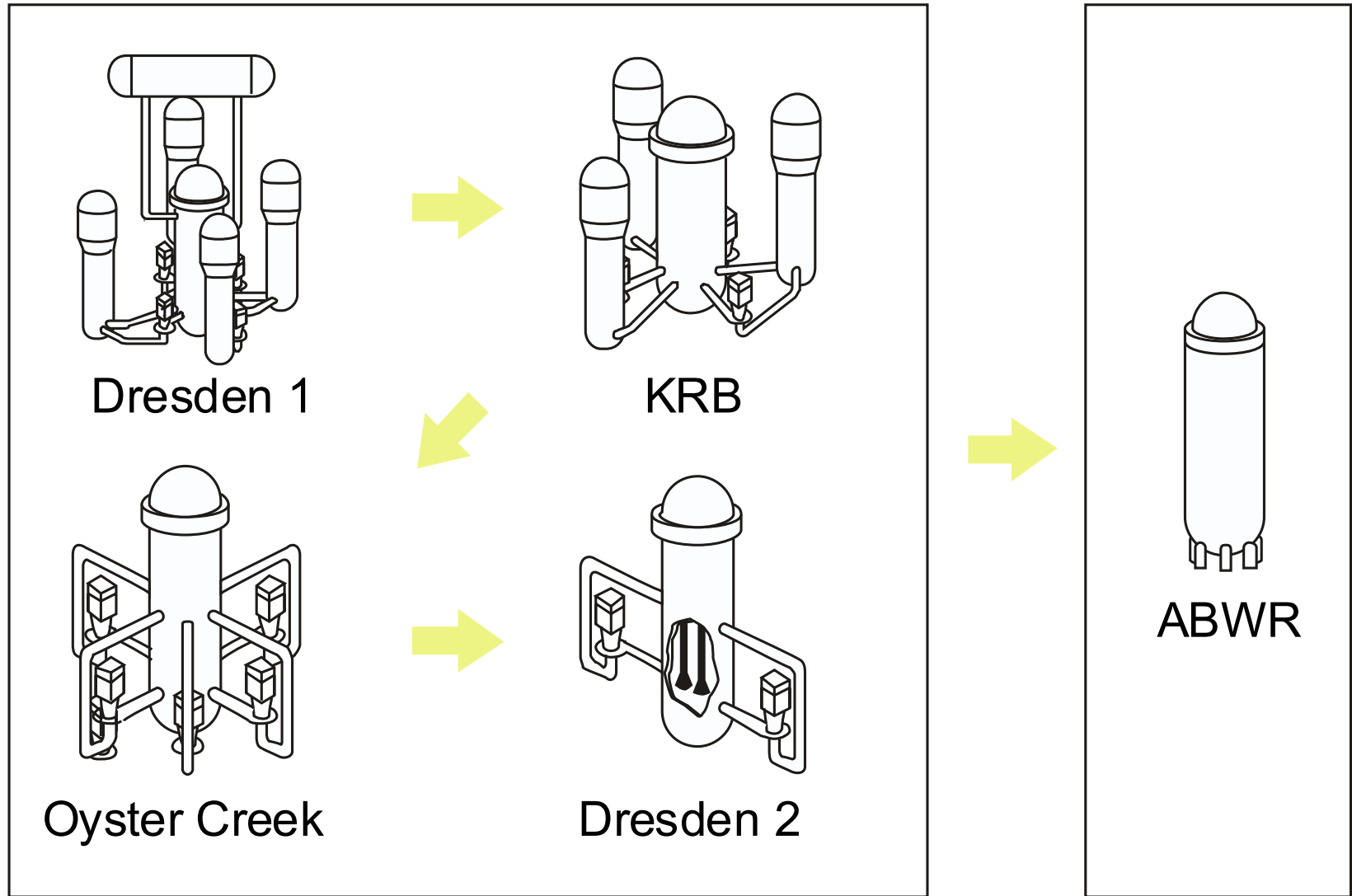
- Operates under saturated conditions
 - Over 40 years of operational experience
 - Operating Pressure is nominally 7.2 MPa (1040 psia) with saturation temperature ~ 287 °C (550 °F)
 - Direct Cycle
 - » Saturated Steam
 - » Quality at exit is greater than 99.9%
 - Higher than most PWRs
 - Evolution

BWR Overview (cont'd)

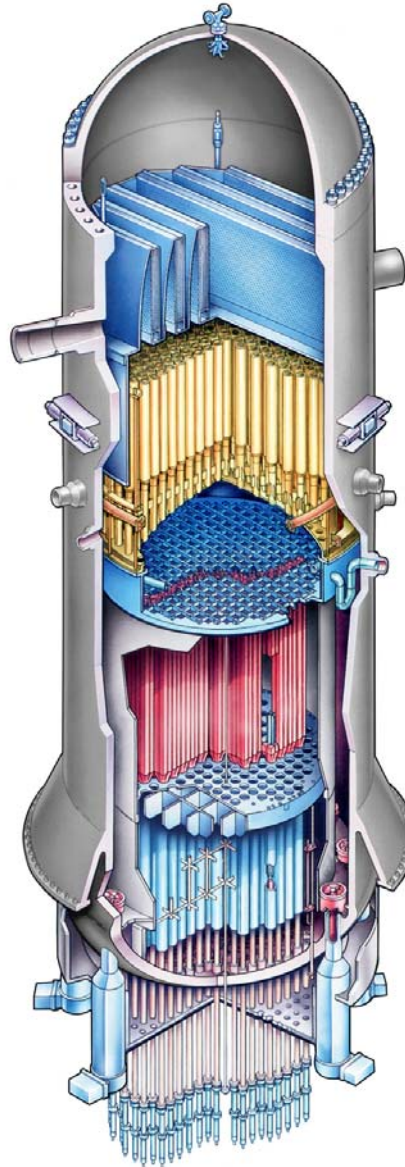
- Power is controlled by positioning control rods & varying core flow
 - Flow control in ABWR provides rapid power changes
 - No Boric Acid as moderator
- ABWR* (and ESBWR) are designed for 100% load rejection without reactor Scram
 - Standard USA ABWR designed for 33% Bypass
 - Can operate in “Island Mode” where licensed

*Lungmen

BWR Evolution



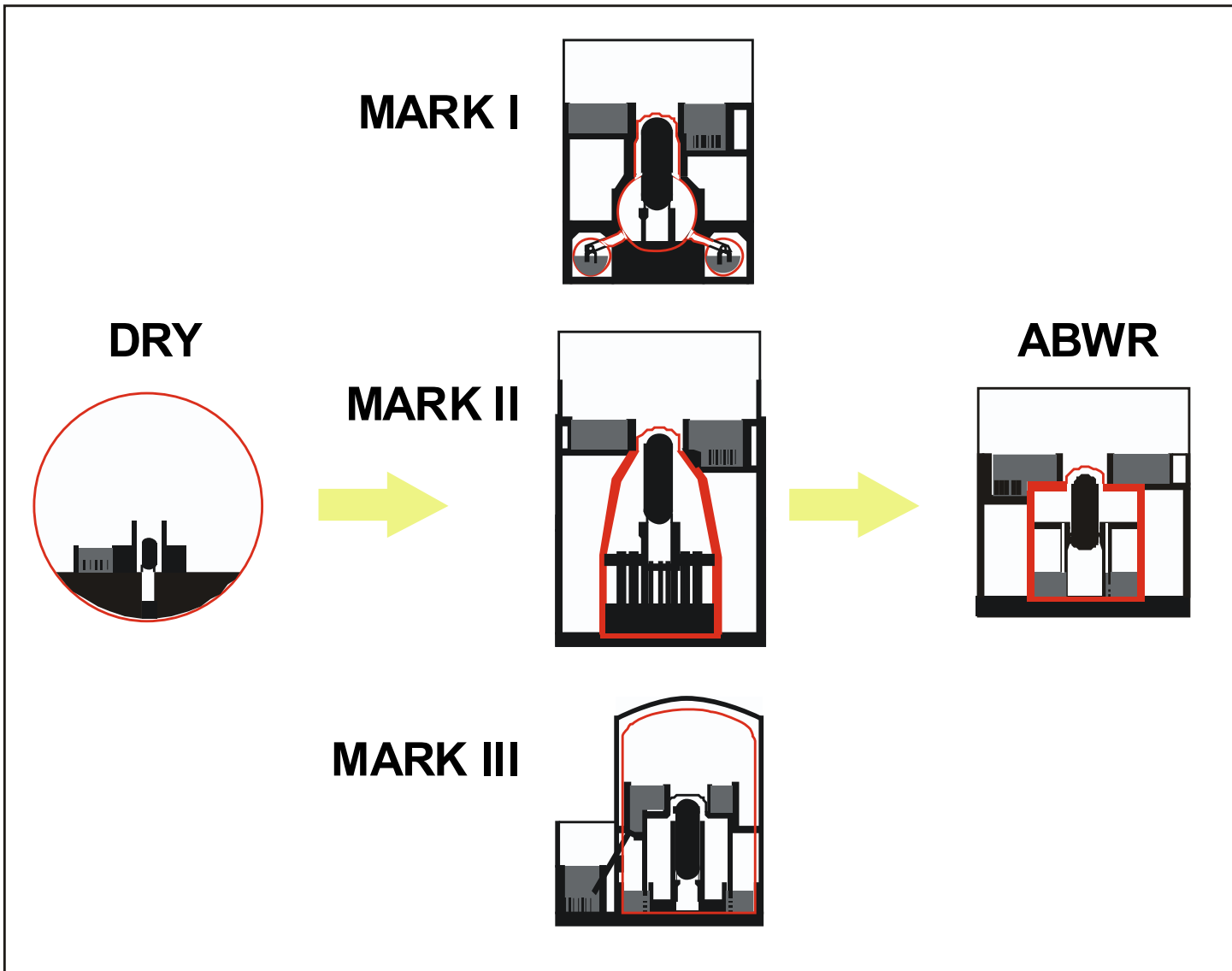
ABWR RPV Assembly



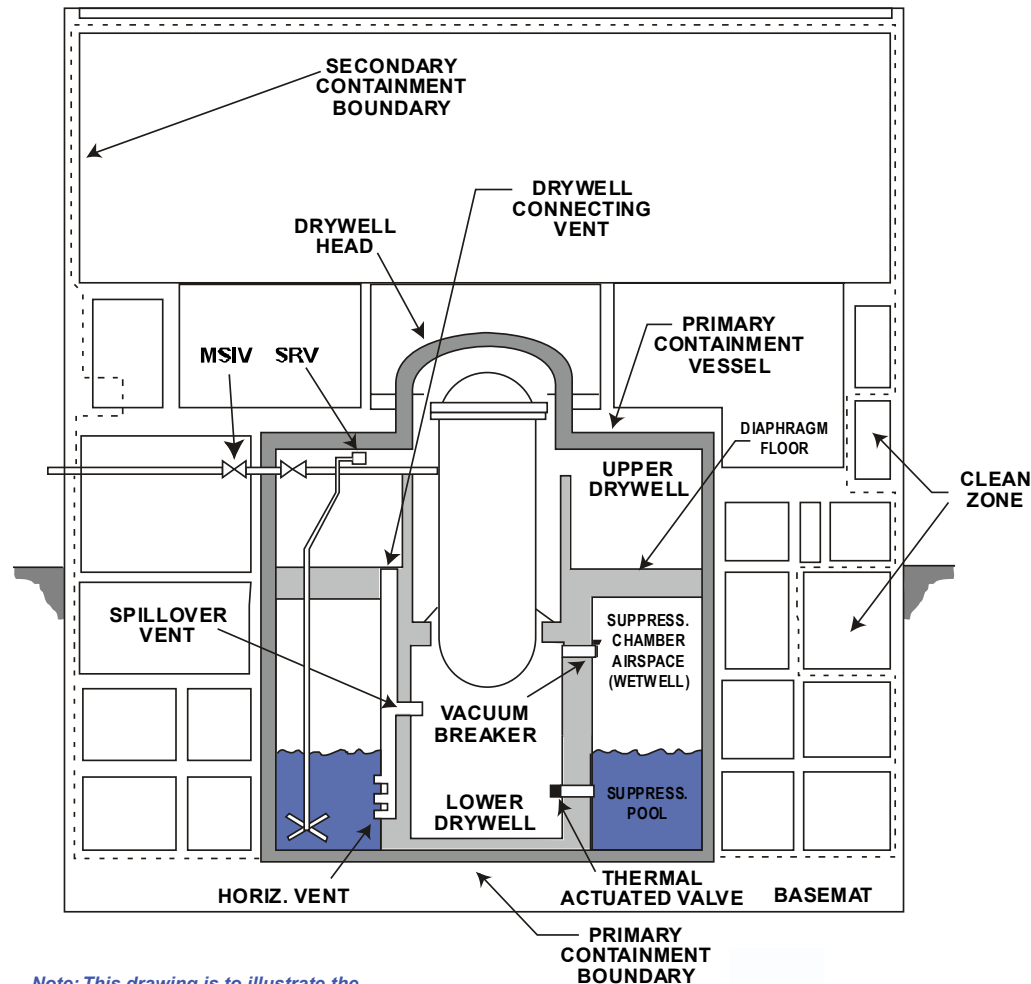
Pressure Suppression Containment

- Reinforced Concrete Containment Vessel
 - Steel Leakage Liner
- Consists of Two Major Elements
 - Drywell
 - » Upper and Lower
 - Wetwell
 - » Suppression pool and airspace
- Inerted with Nitrogen During Operation
- Steam released during accident or transient
 - Routed to Suppression Pool
 - Non-condensable gases are transferred to wetwell airspace

Primary Containment Evolution

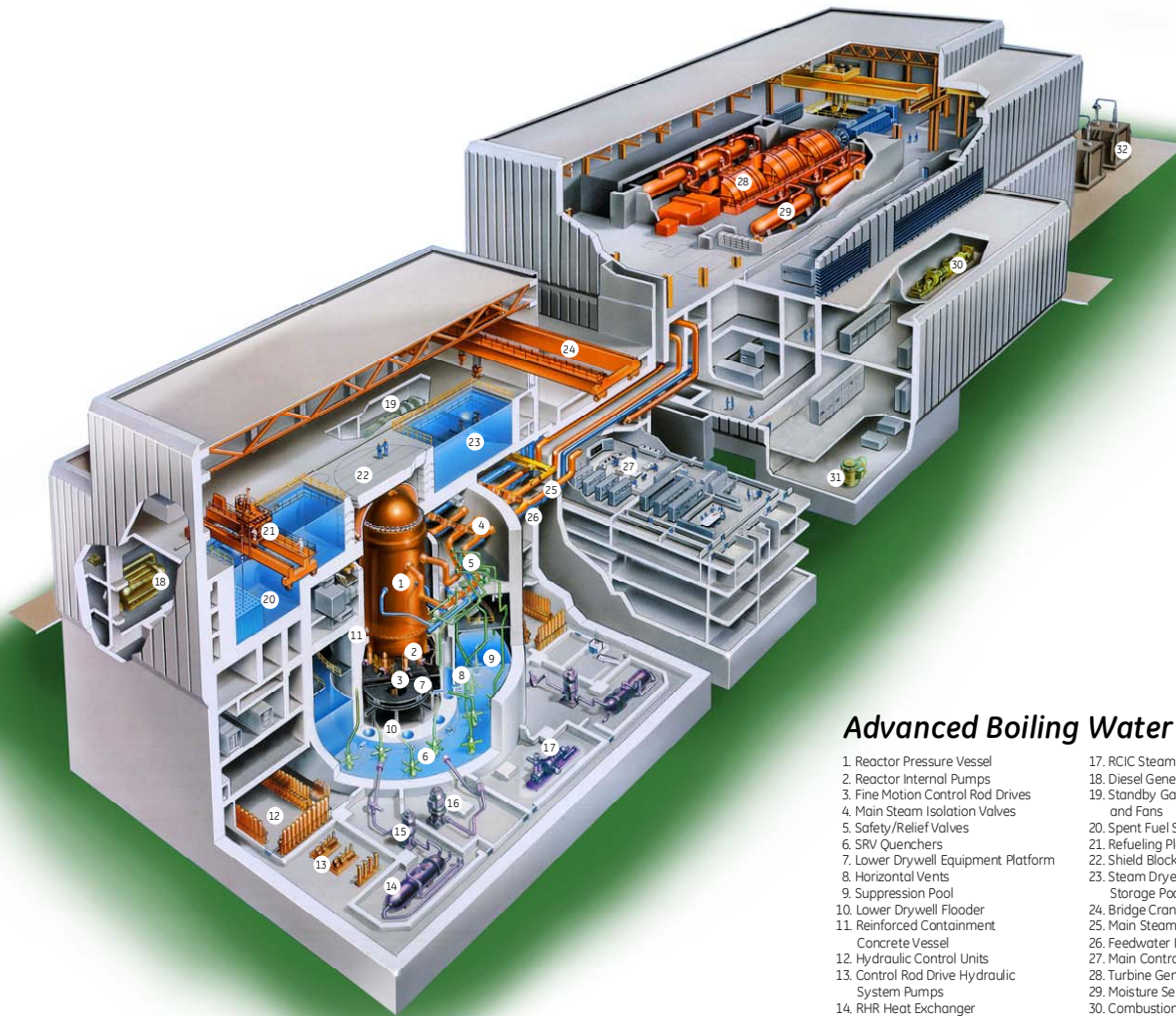


ABWR Reactor Building & Containment



Note: This drawing is to illustrate the scope and requirements of the design and is not intended to show the final detail.

ABWR 3D Cutaway



Advanced Boiling Water Reactor

- | | |
|--|---|
| 1. Reactor Pressure Vessel | 17. RCIC Steam Turbine and Pump |
| 2. Reactor Internal Pumps | 18. Diesel Generator |
| 3. Fine Motion Control Rod Drives | 19. Standby Gas Treatment Filter and Fans |
| 4. Main Steam Isolation Valves | 20. Spent Fuel Storage Pool |
| 5. Safety/Relief Valves | 21. Refueling Platform |
| 6. SRV Quenchers | 22. Shield Blocks |
| 7. Lower Drywell Equipment Platform | 23. Steam Dryer and Separator |
| 8. Horizontal Vents | 24. Storage Pool |
| 9. Suppression Pool | 24. Bridge Crane |
| 10. Lower Drywell Flooder | 25. Main Steam Lines |
| 11. Reinforced Containment Concrete Vessel | 26. Feedwater Lines |
| 12. Hydraulic Control Units | 27. Main Control Room |
| 13. Control Rod Drive Hydraulic System Pumps | 28. Turbine Generator |
| 14. RHR Heat Exchanger | 29. Moisture Separator Reheater |
| 15. RHR Pump | 30. Combustion Turbine Generator |
| 16. HPCF Pump | 31. Air Compressor and Dryers |
| | 32. Switchyard |

Advanced Boiling Water Reactor

- Licensed / Certified in 3 Countries
 - First Design Certified by NRC under Part 52
 - Generation III
- Four operating in Japan
- Several more under construction or planned
 - Japan's BWR for foreseeable future
- Power Level(s)
 - 3,926 MWt (1350 MWe net) US Certified
 - 4,300 MWt (1460 MWe net) FIN5 Offering

ABWR Basic Parameters

- 3,926 Megawatt Core Thermal Power
- ~1,365 Megawatt Electric Gross
 - For nominal summer conditions
- Internal Reactor Recirculation Pumps (RIP)
 - No recirculation piping
 - Canned Rotor Pumps
- 3 Divisions Safety Systems
 - At least 72 hours operators hands-off capability

ABWR Design Parameters

- Designed to bound most potential site in United States
 - Based on EPRI URD recommendations
 - » Extreme Wind
 - » Maximum & Minimum Temperature
 - » Seismic 0.3 g (all soils) in US (0.4 g in Taiwan)
 - » Tornado missiles
- Both 60Hz and 50 Hz

ABWR Site Parameters

- Tornado
 - » 483 km/hr (300 mph)
- Extreme Winds for Safety-Related Structures
 - » 197 km/hr (122 mph)
- Temperatures
 - » 0% exceedance
 - Maximum 46.1°C (115°F), 26.7°C (80°F) w.b. coincident (27.2°C; 81°F)
 - Minimum -40°C (-40°F)
 - » 1% exceedance
 - Maximum 37.8°C (100°F), 25.0 °C (77°F) w.b. (26.7°C; 80°F)
 - Minimum -23.3°C (-10°F)

ABWR Site Parameters

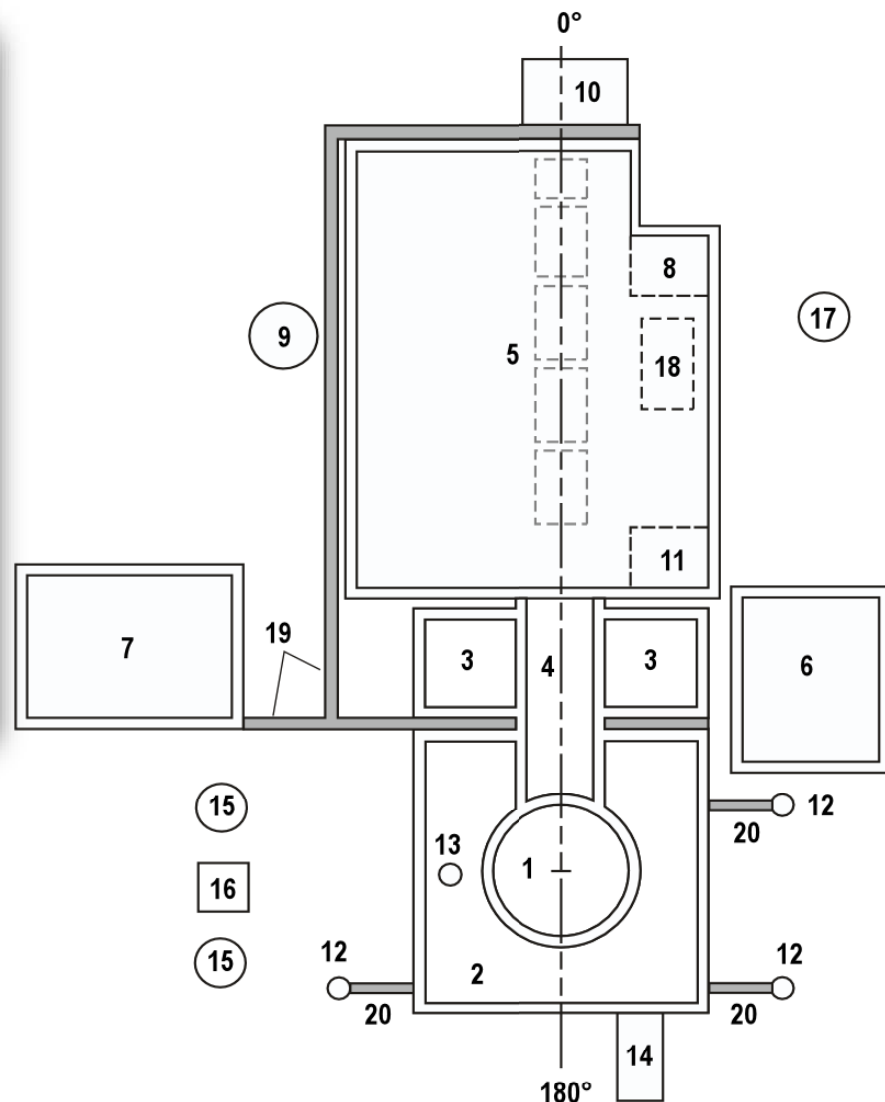
- Soil Bearing Capacity
 - 718 kPa
- Minimum Shear Wave Velocity
 - 300 m/s
- Maximum Site Flood Level
 - 30.5 cm (12 in) below grade
- Maximum ground water level
 - 61 cm (24 in) below grade

Site Specific Design Elements

- Circulating Water System (Power Cycle Heat Sink)
- Ultimate Heat Sink
 - Reactor Service Water (RSW)
 - Safety-related
- Off-site electrical
- Make-up water
- Other site works

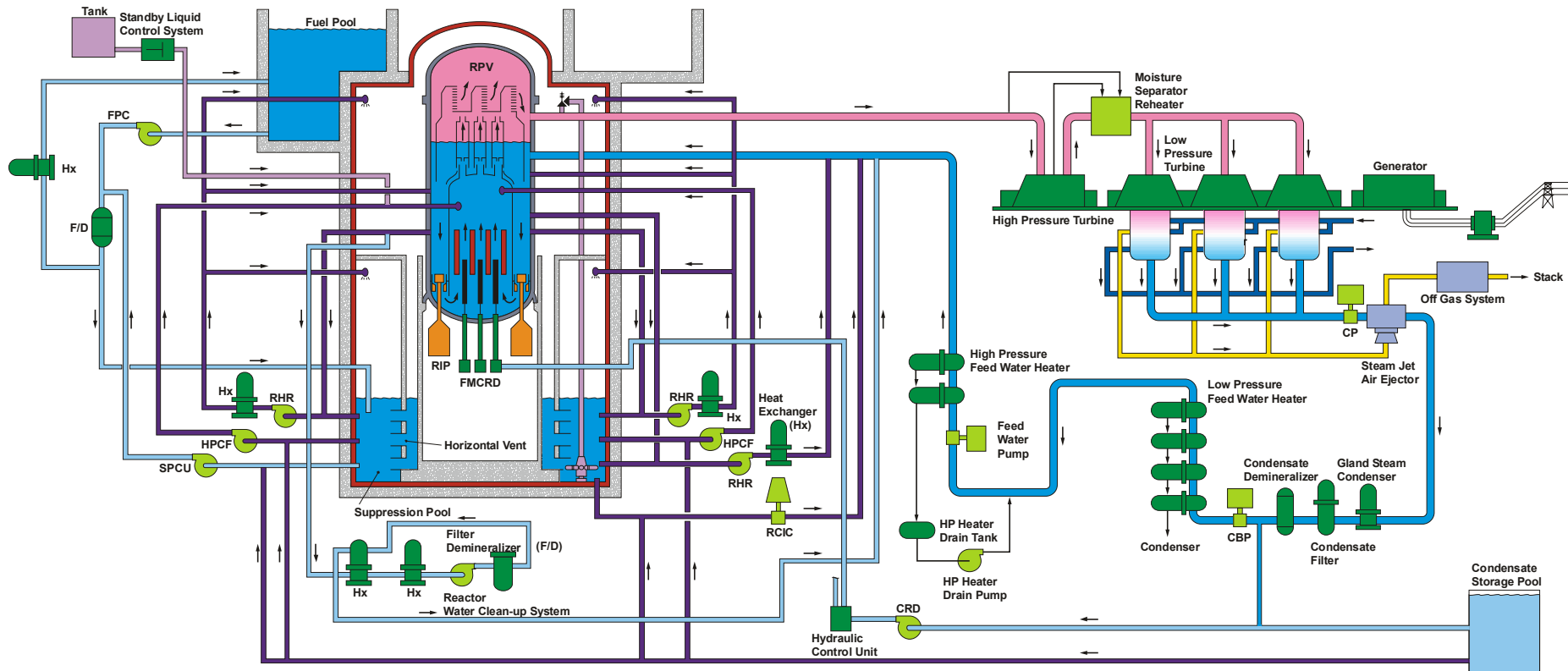
ABWR Site Plan

No.	FACILITY
1	REACTOR CONTAINMENT
2	REACTOR BUILDING
3	CONTROL BUILDING
4	MAIN STEAM / FEEDWATER TUNNEL
5	TURBINE BUILDING
6	SERVICE BUILDING
7	RADWASTE BUILDING
8	HOUSE BOILER
9	CONDENSATE STORAGE TANK
10	UNIT AUXILIARY TRANSFORMERS
11	NORMAL SWITCHGEAR
12	DIESEL OIL STORAGE TANK (3)
13	STACK
14	EQUIPMENT ENTRY LOCK
15	FIRE PROTECTION WATER STORAGE TANK (2)
16	FIRE PROTECTION PUMPHOUSE
17	BUNKER FUEL TANK
18	COMBUSTION TURBINE GENERATOR
19	RADWASTE TUNNELS RB, CB, TB
20	DG OIL TRANSFER TUNNEL (3)



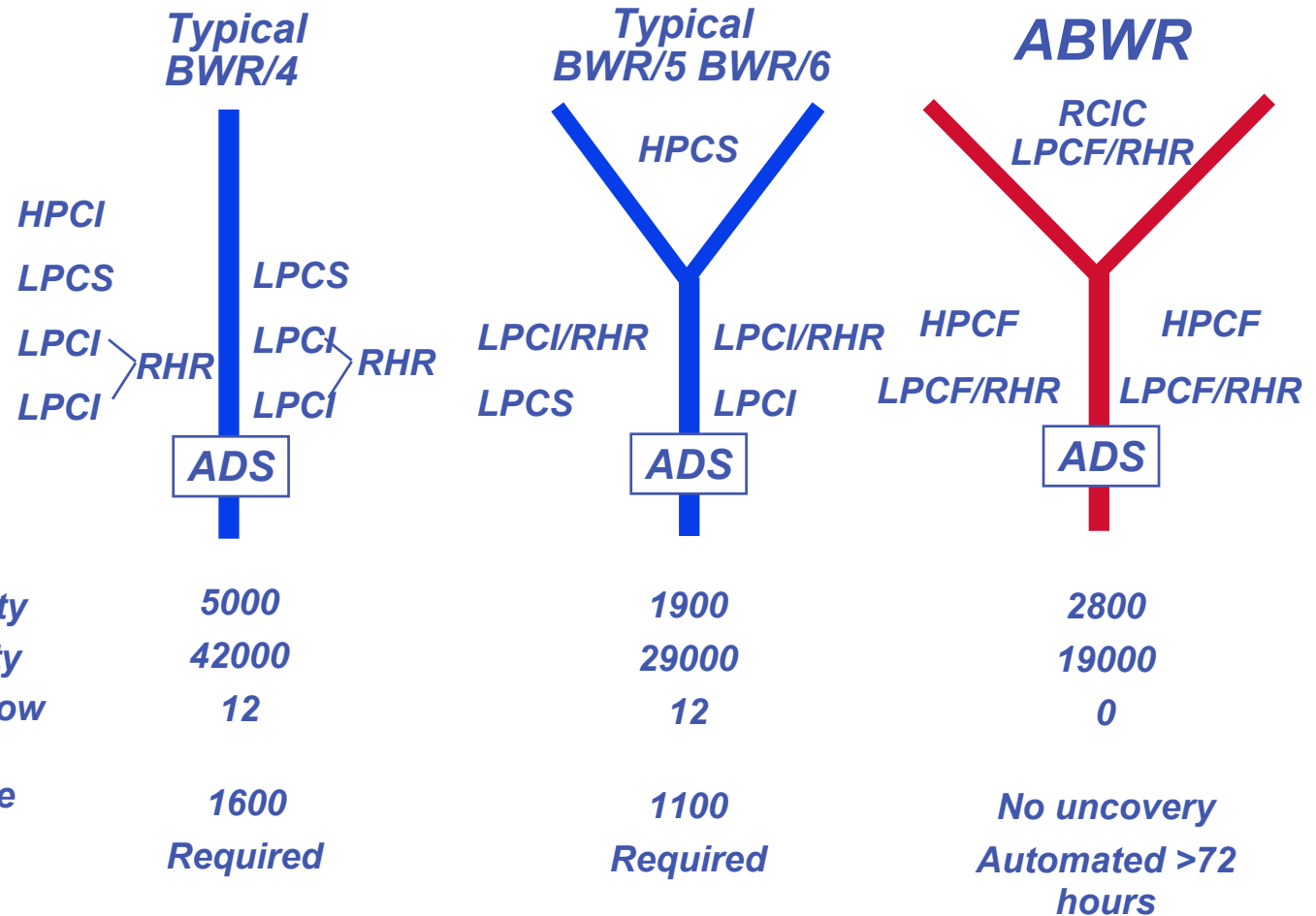


ABWR Overall Flowchart



Emergency Core Cooling

ECCS Systems Evolution



Engineered Safety Features

- Redundancy and Diversity
 - Three Divisions each having high & low pressure pumps:
 - » High Pressure
 - Two Motor-driven High Pressure Core Flooder (HPCF)
 - One Steam-driven Reactor Core Isolation Cooling System (RCIC)
 - » Low Pressure
 - Automatic Depressurization System (ADS)
 - Residual Heat Removal
 - » Low Pressure Flooder Mode (LPFL)
 - » Suppression Pool Cooling
 - » Containment Spray

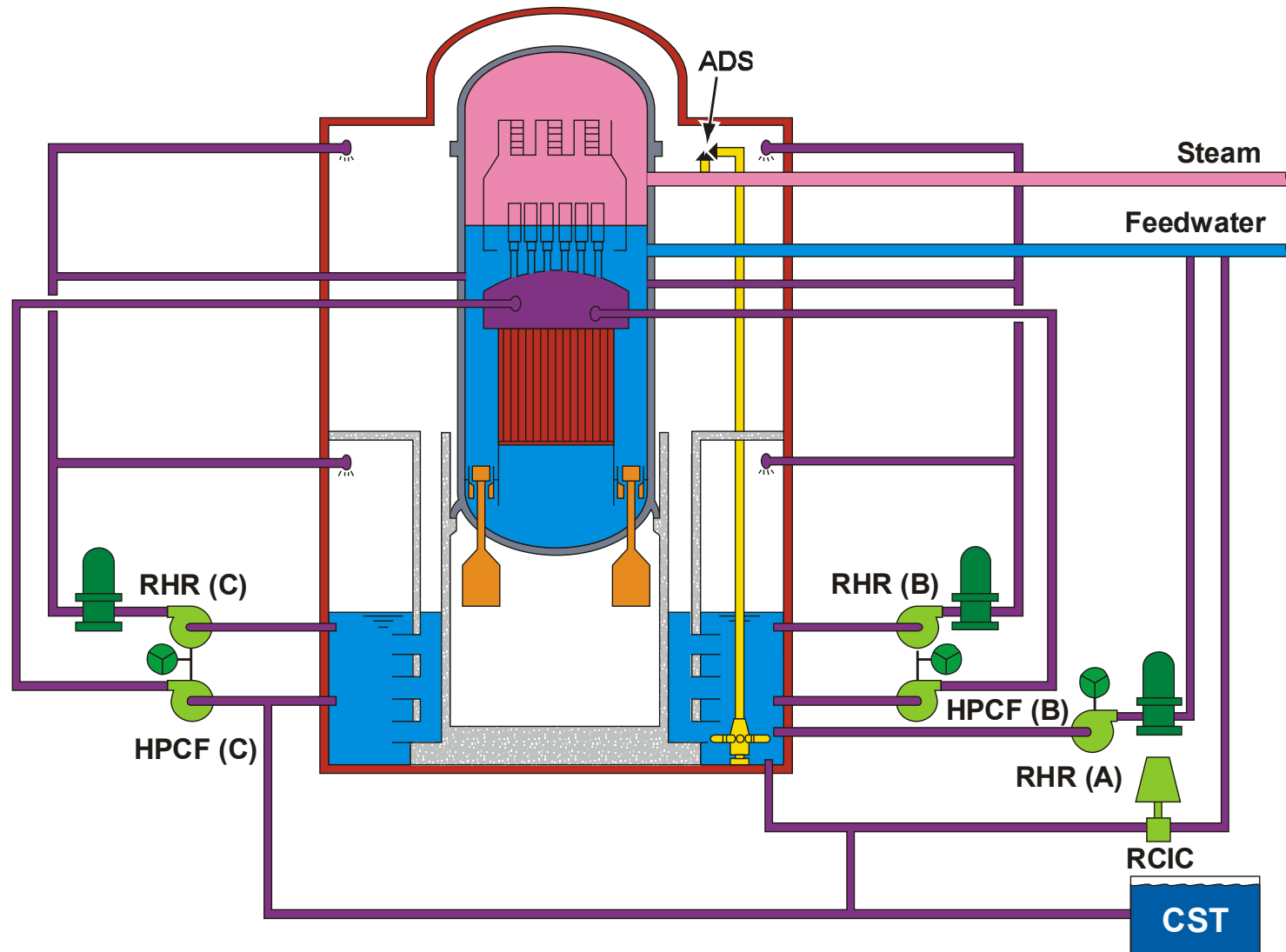
ABWR ECCS Improvements

- Three completely separate mechanical & electrical divisions
 - Core cooling
 - Heat removal
 - Emergency Diesel Generators
- Station BlackOut (SBO) addressed
 - Steam-driven RCIC
 - Combustion turbine-generator
 - Fire system cross-tie
- Automation of Suppression Pool cooling function
 - Heat exchangers always in the loop

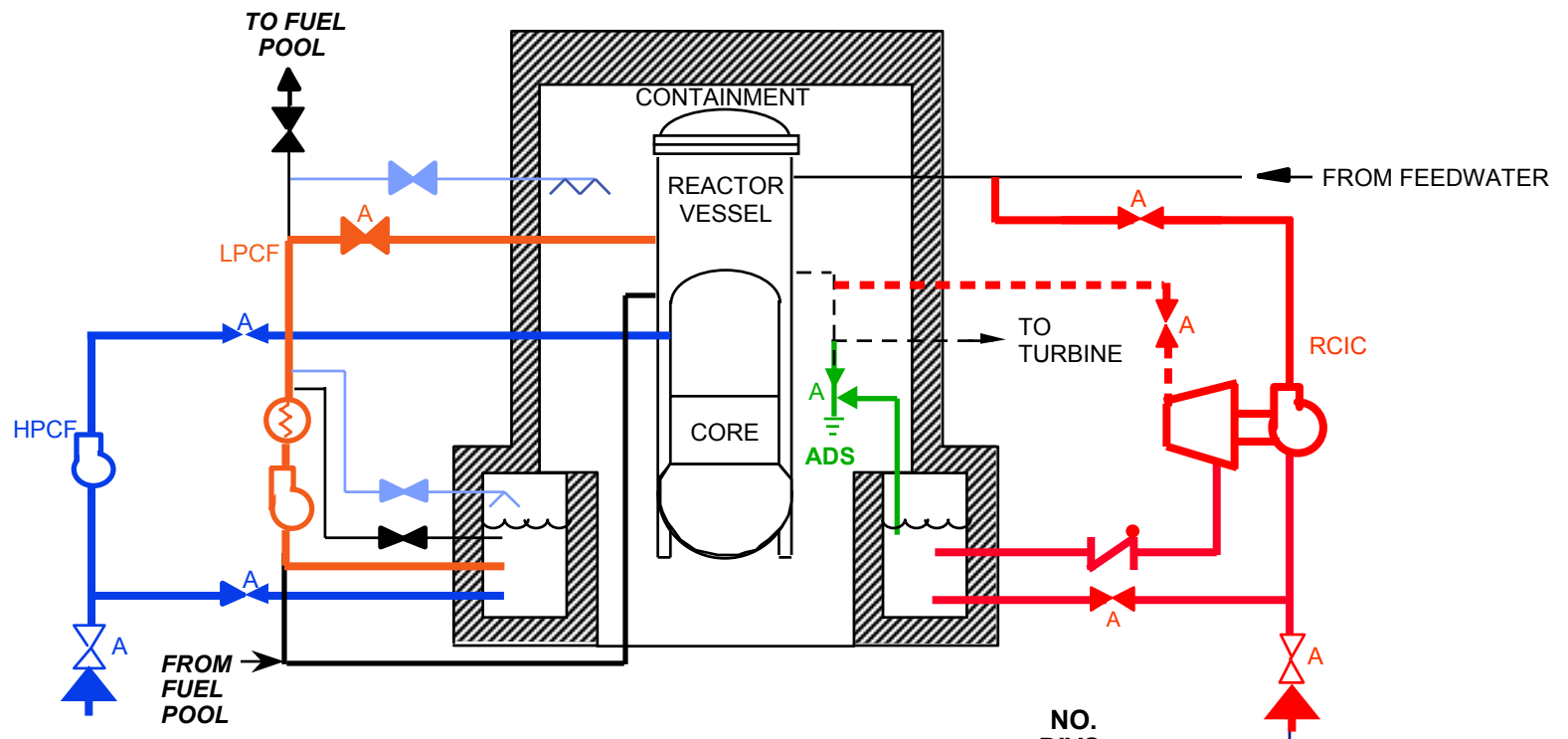
ABWR ECCS Improvements (cont'd)

- Elimination/transfer of complex modes
 - Reduced valves, pipes by one-third
- Significant capacity reduction
- Greatly reduced duty during transients
 - N-2 Capability at high pressure
- Improved small break response
 - Reduced needs for ADS
- No fuel uncover for any pipe break
- Low pressure piping/equipment design pressure raised to 40% of operating pressure to resolve ISLOCA concerns

ABWR ECCS



ABWR Emergency Core Cooling Systems



FROM
CONDENSATE
STORAGE

FUNCTION

- **HIGH PRESSURE CORE FLOODER**
- **REACTOR CORE ISOLATION COOLING**
- **AUTOMATIC DEPRESSURIZATION SYS.**
- **LOW PRESSURE CORE FLOODER**
- SUPPRESSION POOL COOLING
- WETWELL SPRAY
- DRYWELL SPRAY
- **SHUTDOWN COOLING**
- FUEL POOL COOLING SUPPORT

TYPE

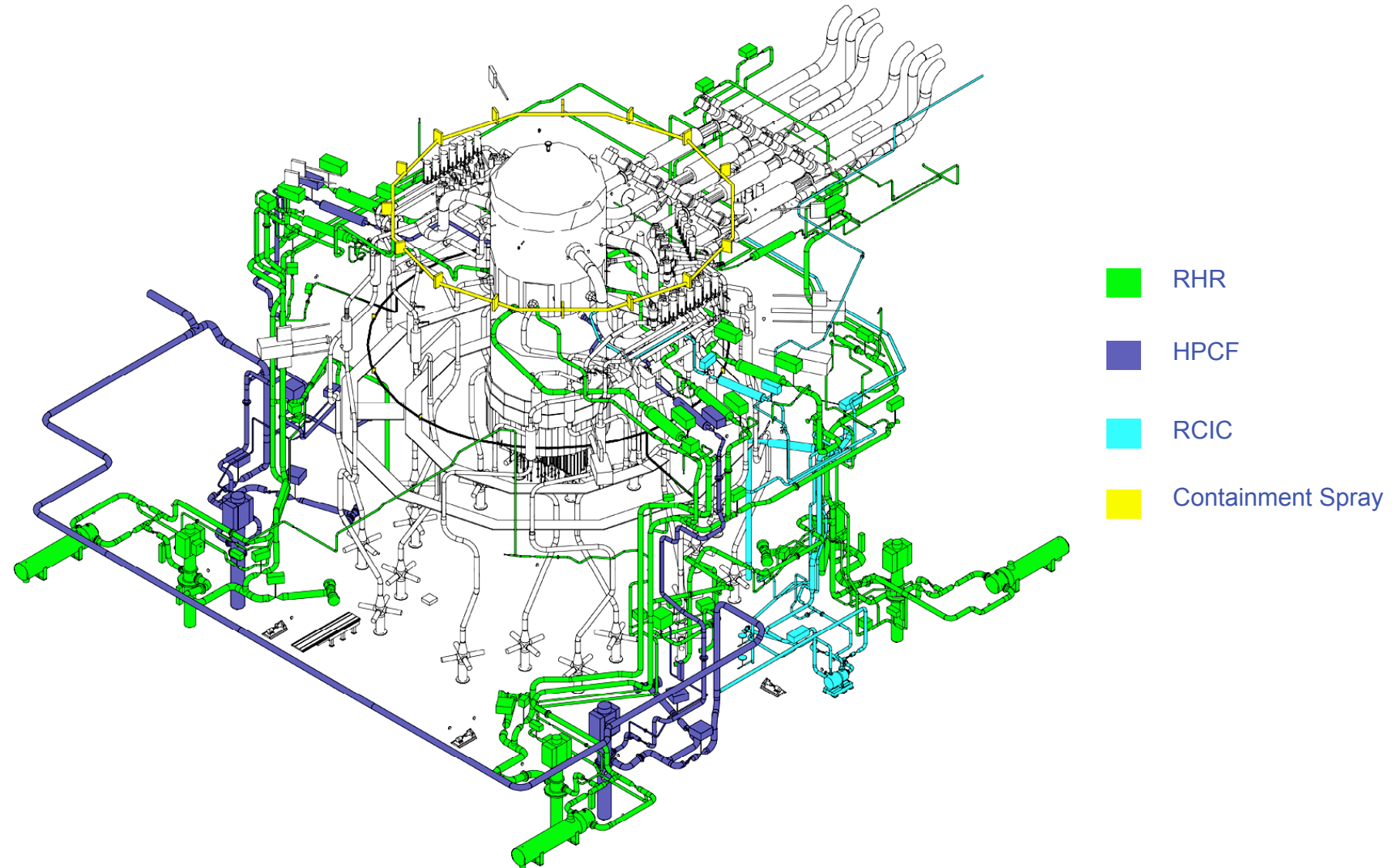
AUTO
AUTO
AUTO
AUTO
AUTO
MAN
MAN
MAN
MAN

NO. DIVS.

2
1
2
3
3
2
2
3
2

FROM
CONDENSATE
STORAGE

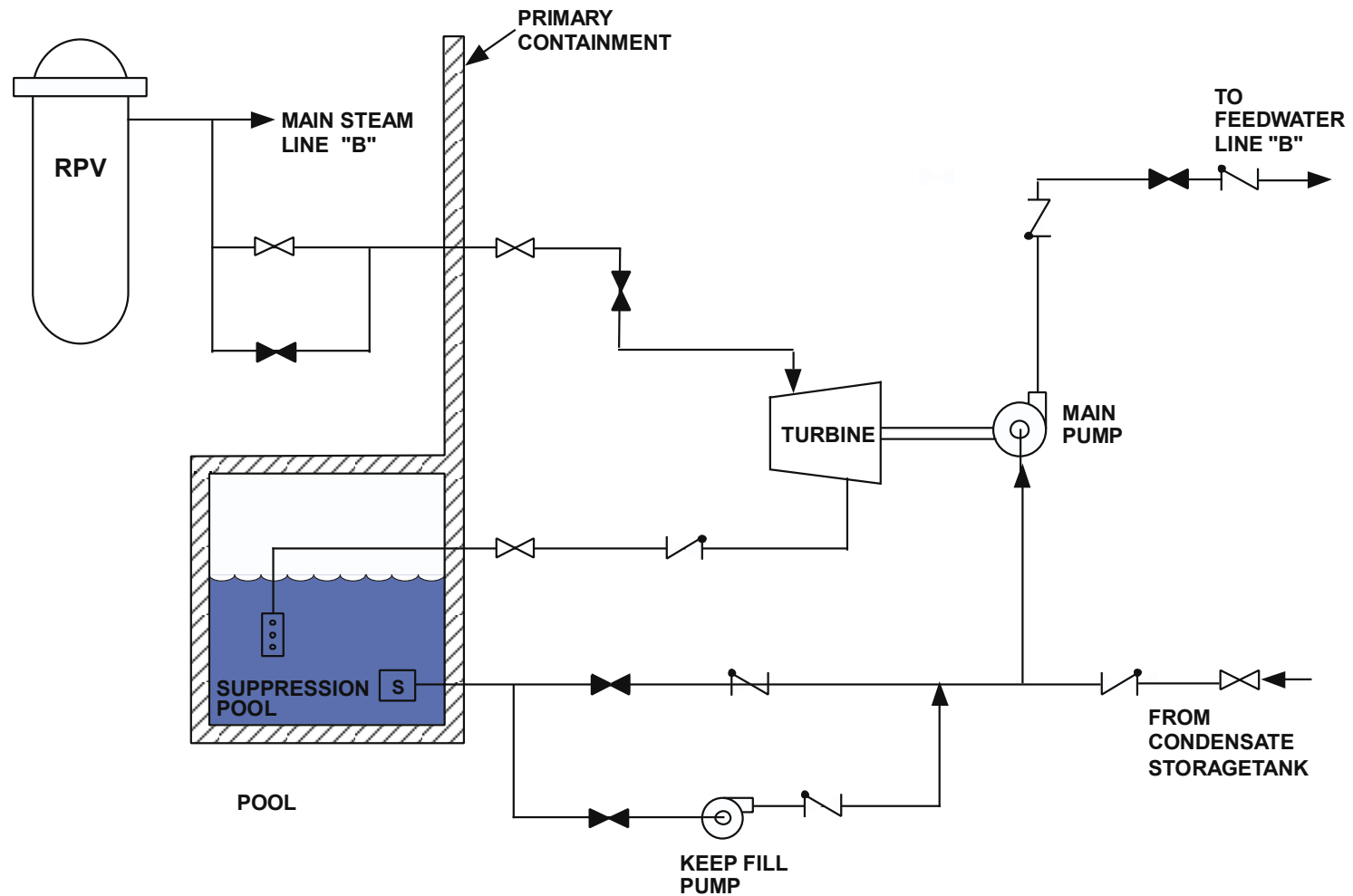
ABWR ECCS Piping



Reactor Core Isolation Cooling (RCIC)

- **Purpose:** Provide makeup water to RPV when it's isolated from FeedWater (FW) system. Also part of ECCS.
- Steam-driven High Pressure Pump
 - Flow is $\sim 182 \text{ m}^3$ per hour (800 gpm)
 - » Provides sufficient makeup on loss of FW without need for any other makeup system
 - » Auto initiates at RPV Water Level 2
- AC independent system
 - Batteries for electrical operation
 - Steam for motive power
- Mitigates Station BlackOut (SBO) events
- 2 water sources
 - Suppression Pool (safety)
 - Condensate Storage Tank (preferred)

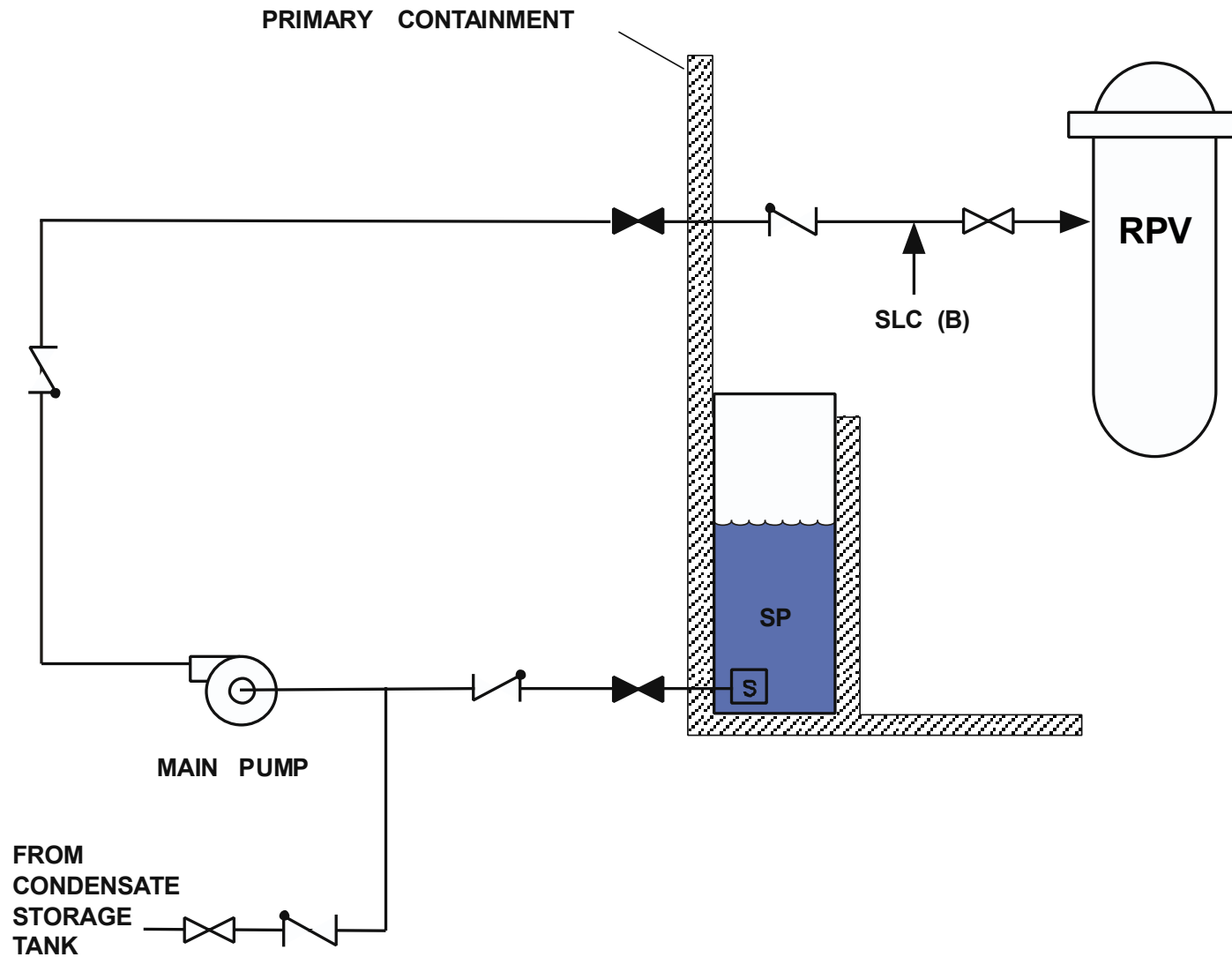
ABWR RCIC



High Pressure Core Flooder (HPCF)

- 2 Motor-driven High Pressure Pumps
 - Flow is $\sim 182 \text{ m}^3$ per hour (800 gpm) at rated pressure
 - » Backs up RCIC for level transients
 - » Auto initiates at RPV Water Level 1.5
 - Flow is 727 m^3 per hour (3200) when vessel is depressurized
 - » Single pump operating ensures no core damage
- 2 water sources
 - Suppression Pool (safety)
 - Condensate Storage Tank (preferred)

ABWR HPCF



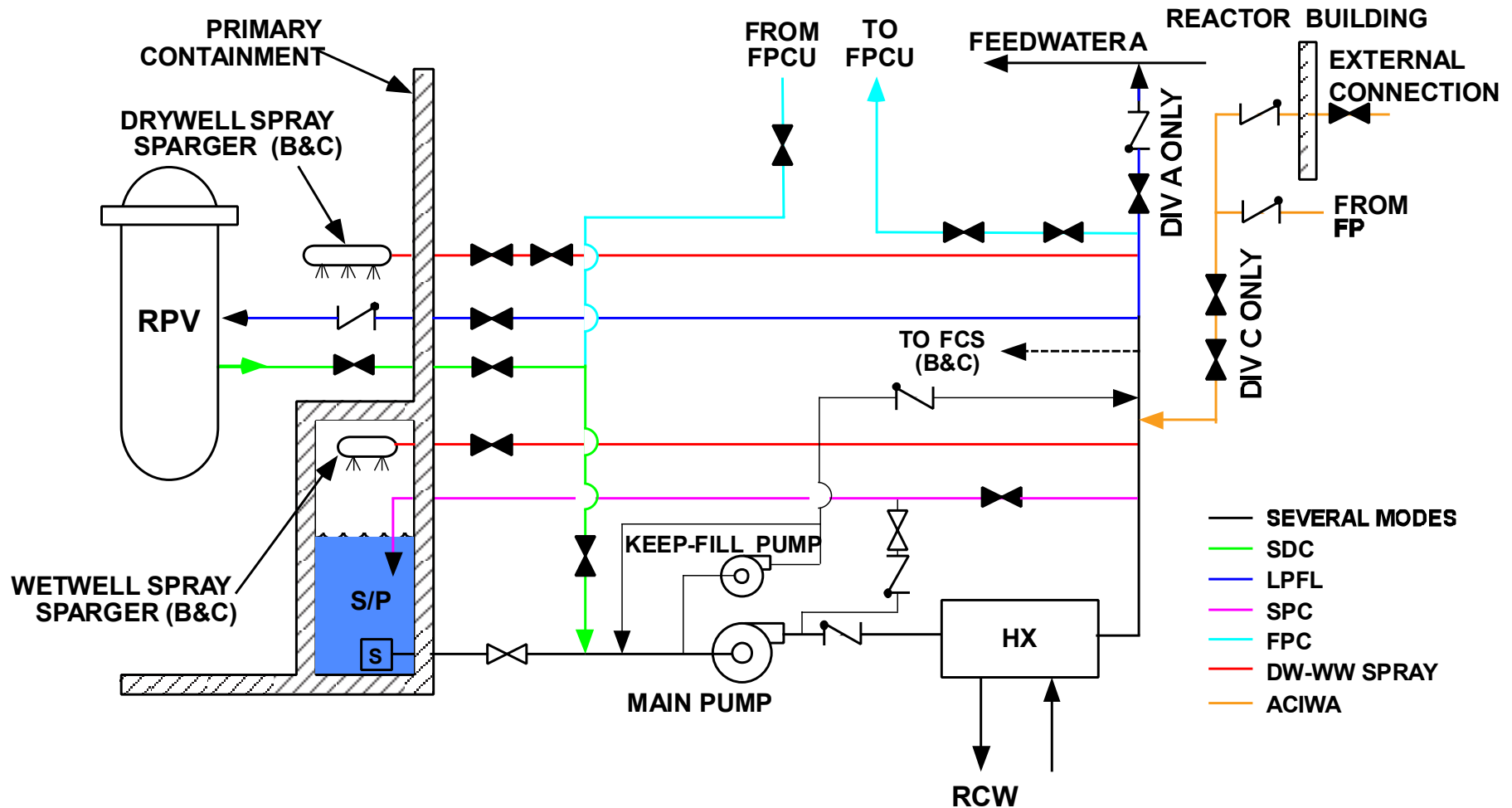
Residual Heat Removal (RHR)

- Six Different Modes of Operation
 - Safety-related modes
 - » Low Pressure Flooder (LPFL)
 - » Suppression Pool Cooling
 - » Containment Spray
 - Non-safety
 - » Shutdown Cooling
 - » Fuel Pool Cooling Support
 - » AC Independent Water Addition (Fire Water)

Residual Heat Removal (cont'd)

- Recirculates & cools water inside Primary Containment
- 3 Motor-driven Low Pressure Pumps
 - Flow is 954 m³ per hour (4200 gpm) when vessel is depressurized
 - » Single pump operating ensures no core damage
- 1 water source
 - Suppression Pool (safety)

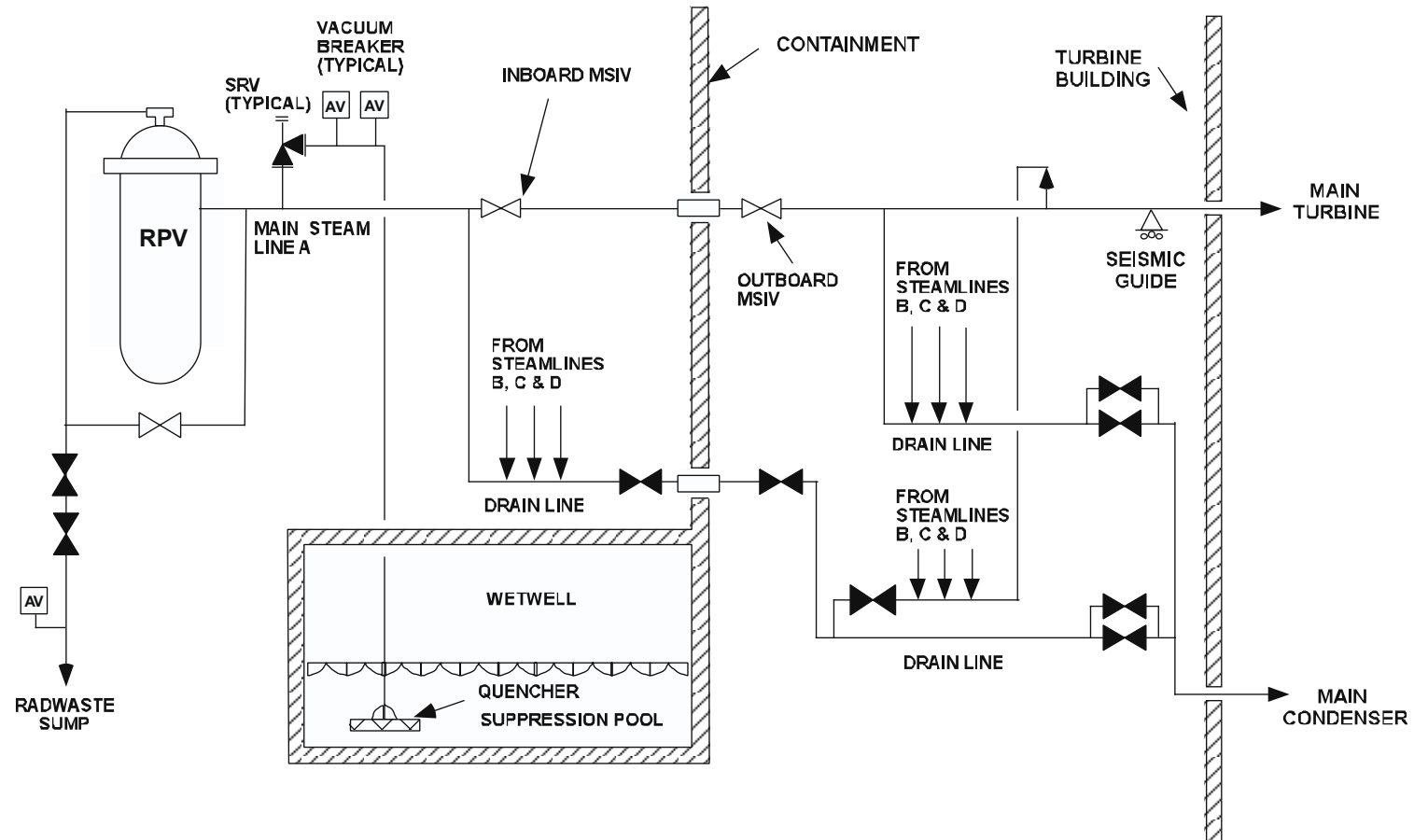
ABWR RHR

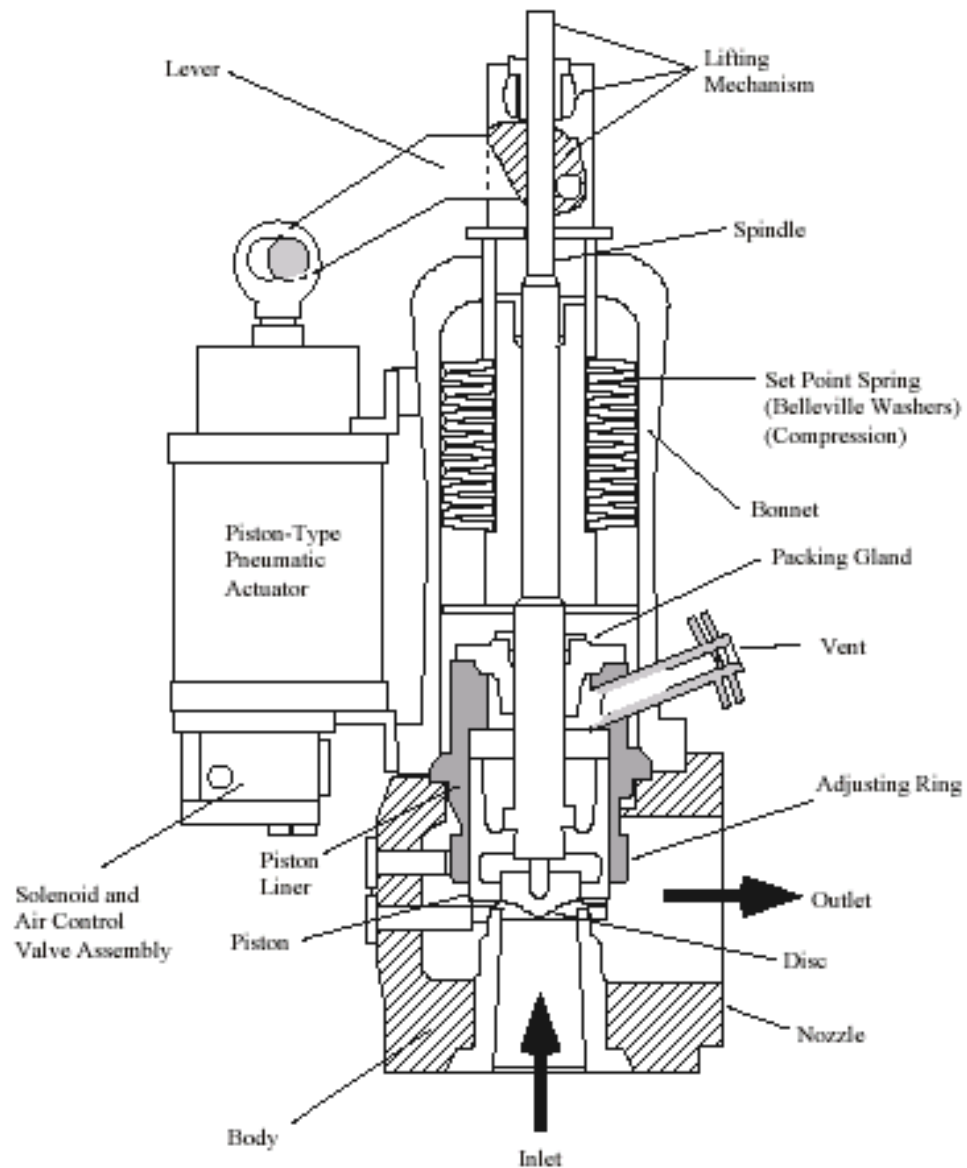


Automatic Depressurization System (ADS)

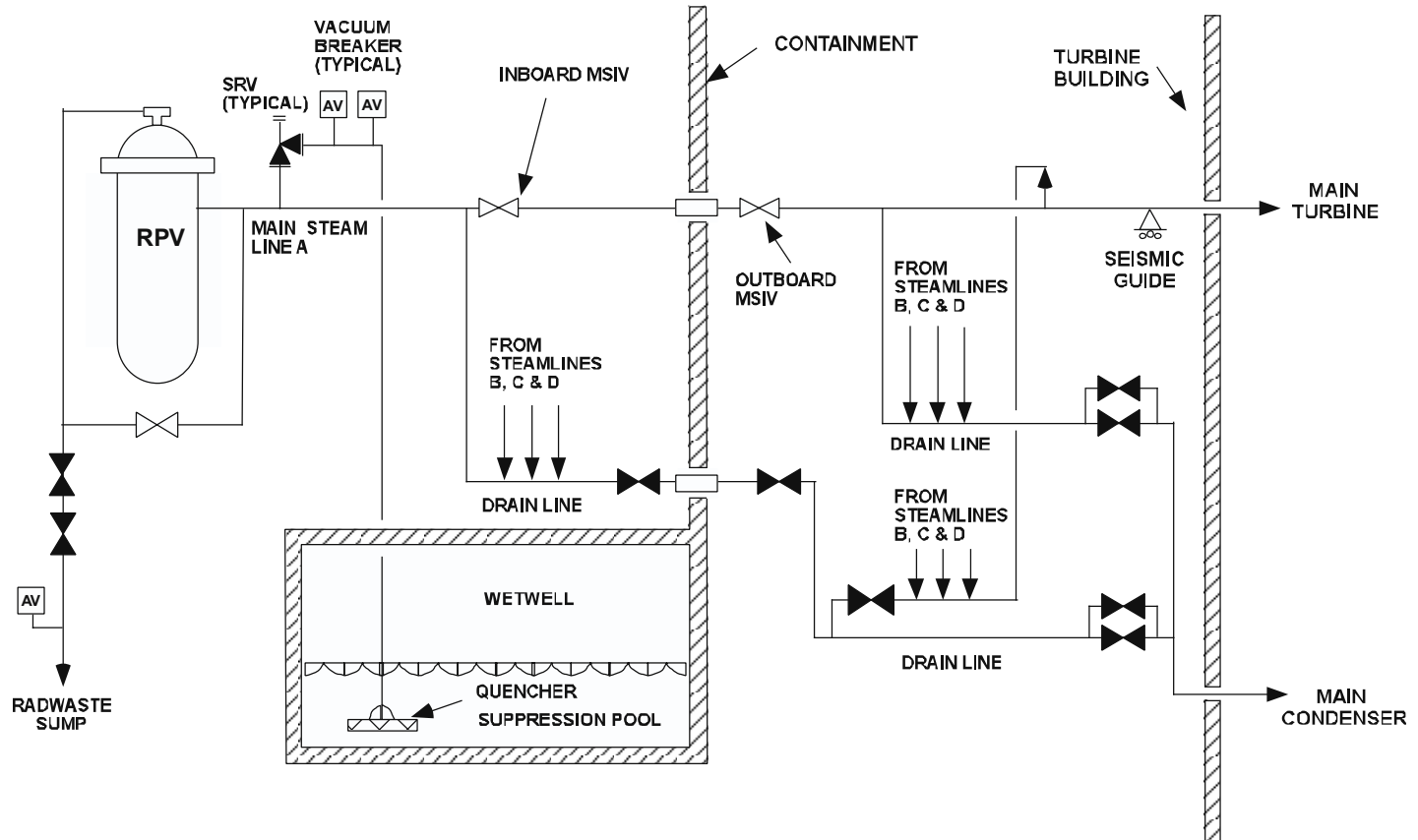
- 8 of 18 Safety Relief Valves (SRVs)
 - 2 SRVs on each Main Steam Line
 - Each SRV blowdowns to quencher in Suppression Pool
 - » Spring Safety mode for code pressure protection
 - » Externally actuated for Relief mode
 - Pressure transient mitigation

Automatic Depressurization System

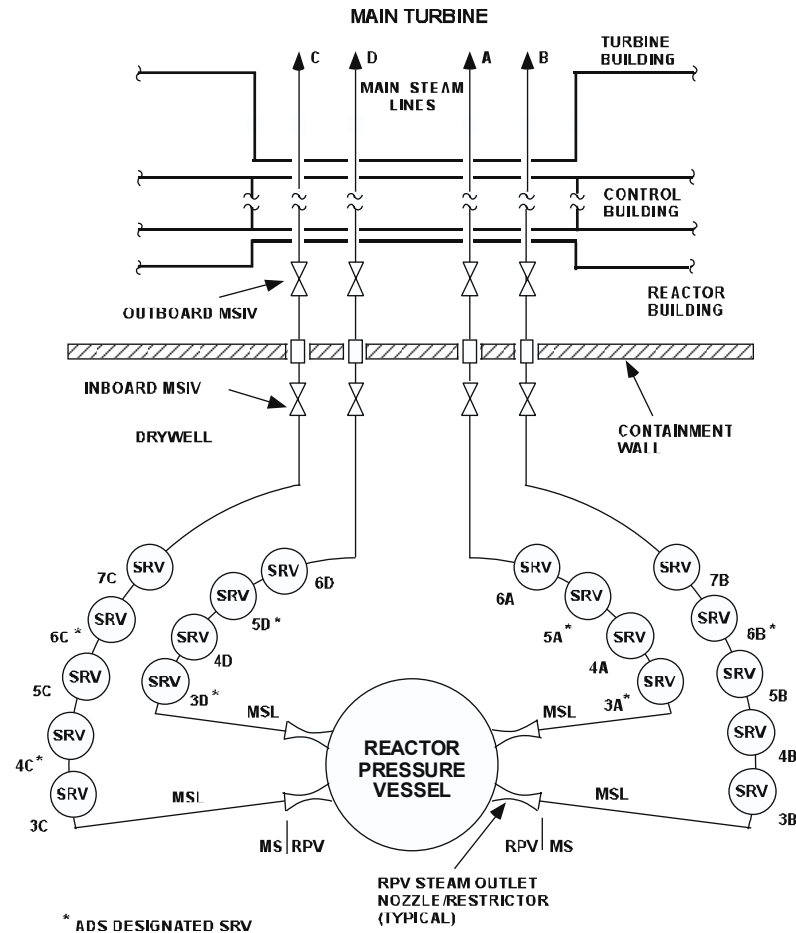




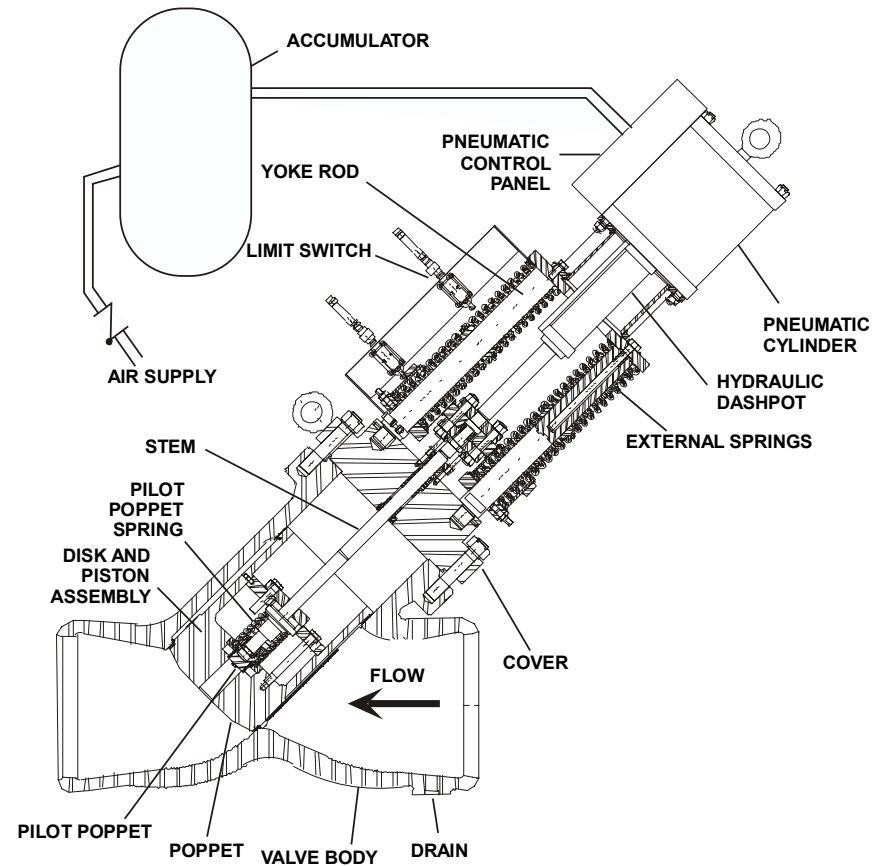
Main Steam Schematic



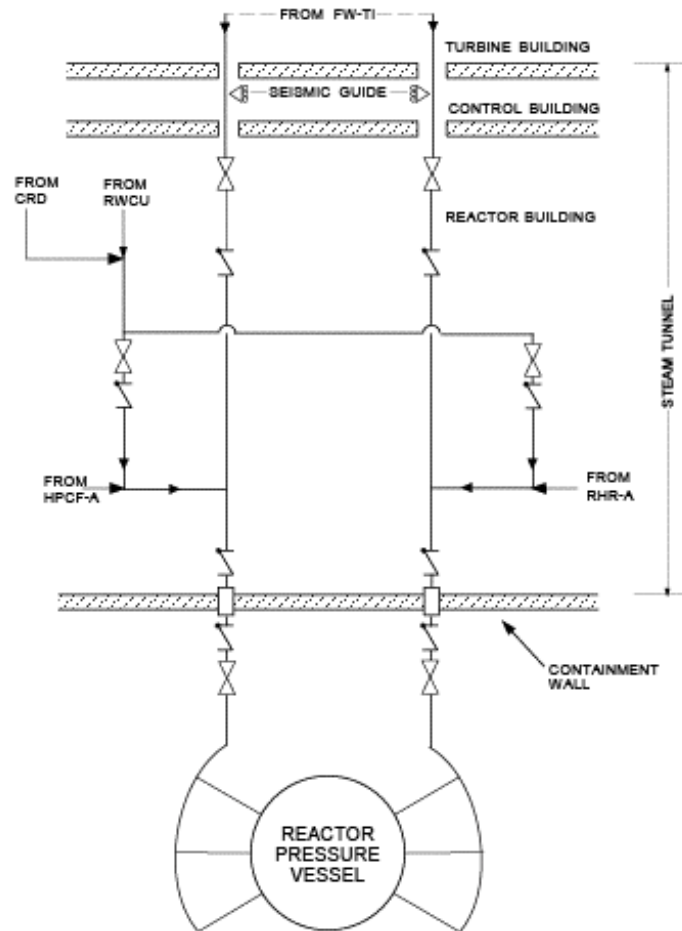
MSIV, SRV configuration



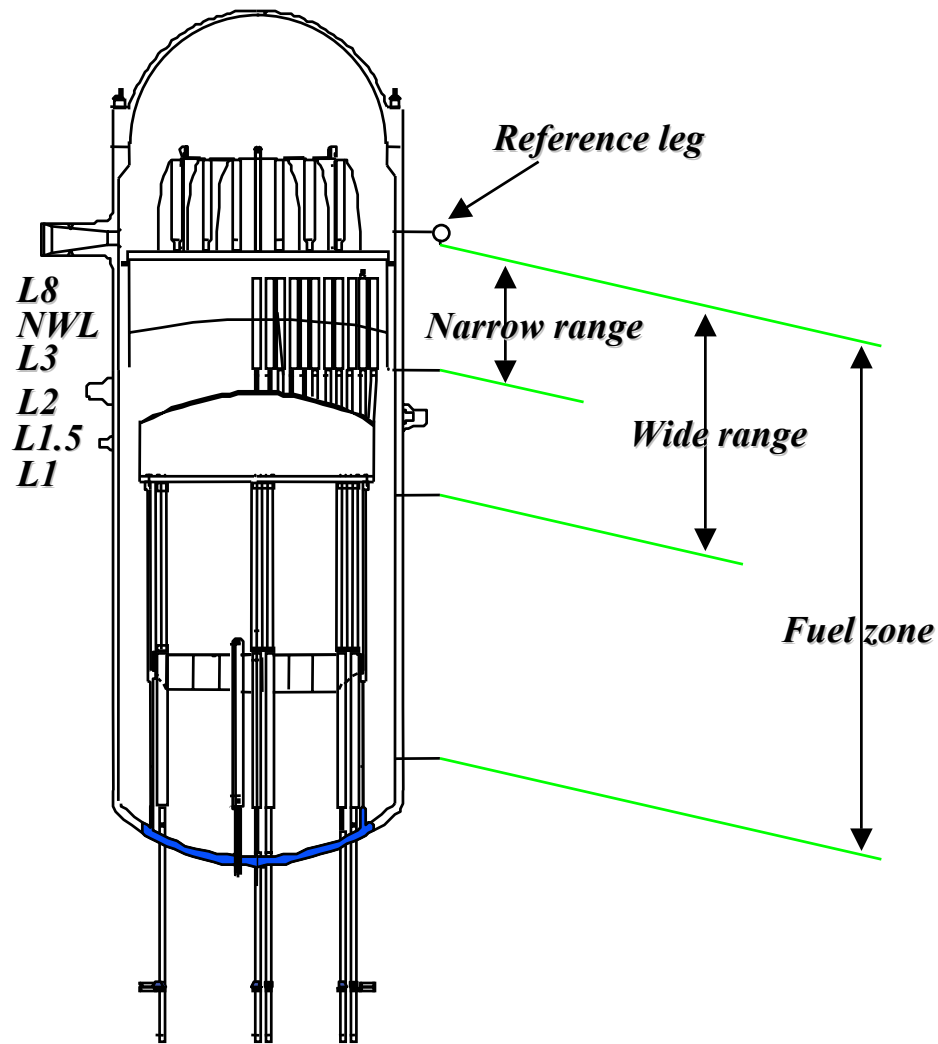
MSIVs



Feedwater (nuclear side)



BWR Water Level Measurement



- **L8 - Turbine trip, MSIV close**
- **L3 - Scram**
- **L2 - RCIC start**
- **L1.5 - HPCF start**
- **L1 - Remaining ECCS start (i.e., LPFL, ADS)**

Reactor Building Cooling Water (RCW)

Reactor Building Service Water (RSW)

- **RCW Purpose:** Provide cooling to various systems in Nuclear Island
- **RSW Purpose:** Transfer heat from RCW HXs to Ultimate Heat Sink

Reactor Building Cooling Water (RCW)

Reactor Building Service Water (RSW)

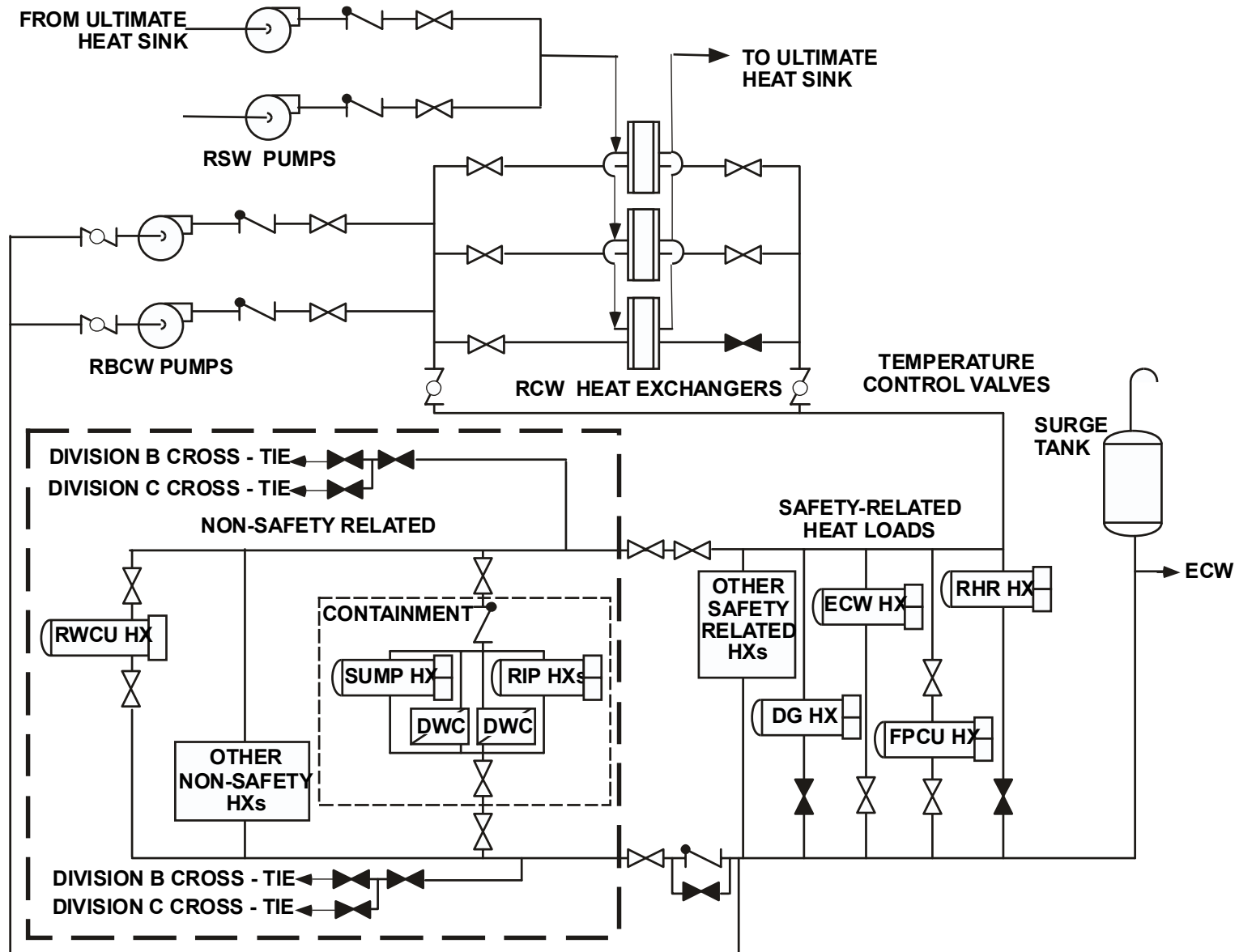
RCW

- Three separate safety divisions cool:
 - ECCS, EDGs, HVAC Emergency Chilled Water (HECW)
 - Non-safety systems: RIPs, RWCU, FPCU, DWC, etc.
 - » Isolated on LOCA Signal
 - Each division has HXs & two 50% Pumps
 - » Normally One Pump Operation
 - » 2nd Pump Auto Starts on LOCA Signal

RSW

- Each division has HXs & two 100% Pumps
- Flat Plate HXs for easier maintenance & better performance

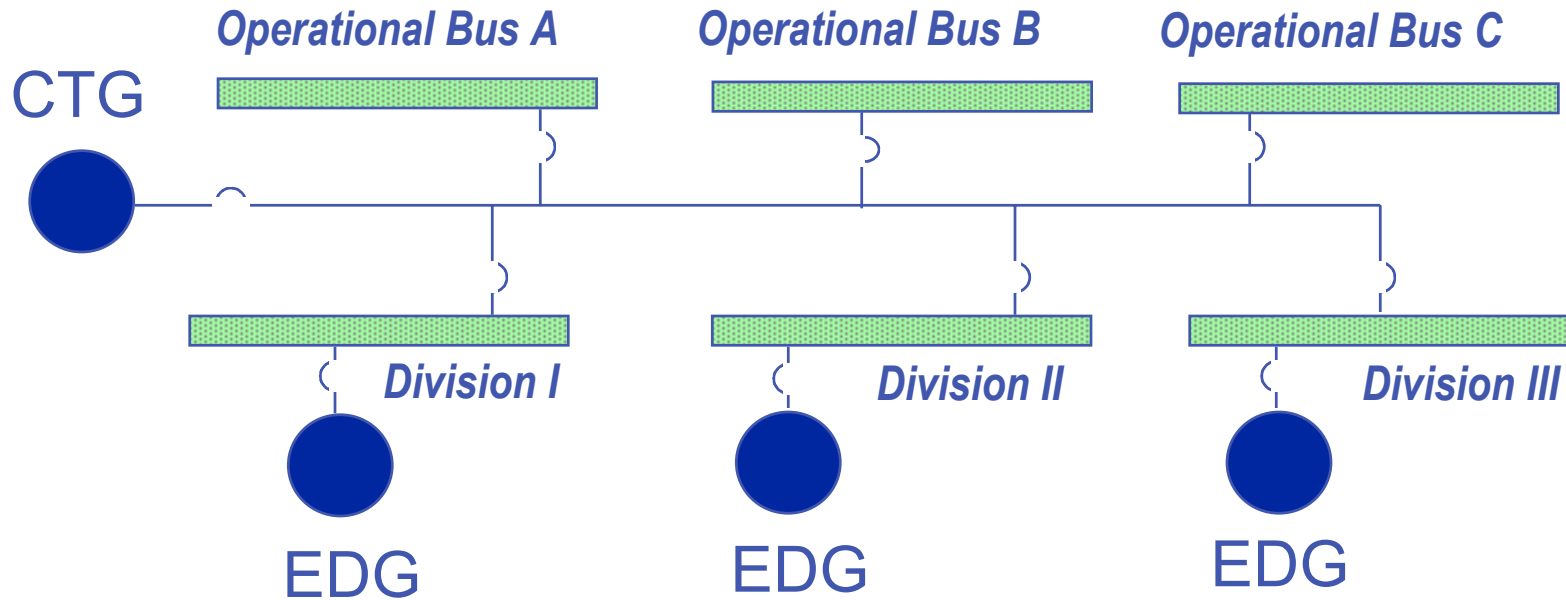
ABWR RCW - RSW



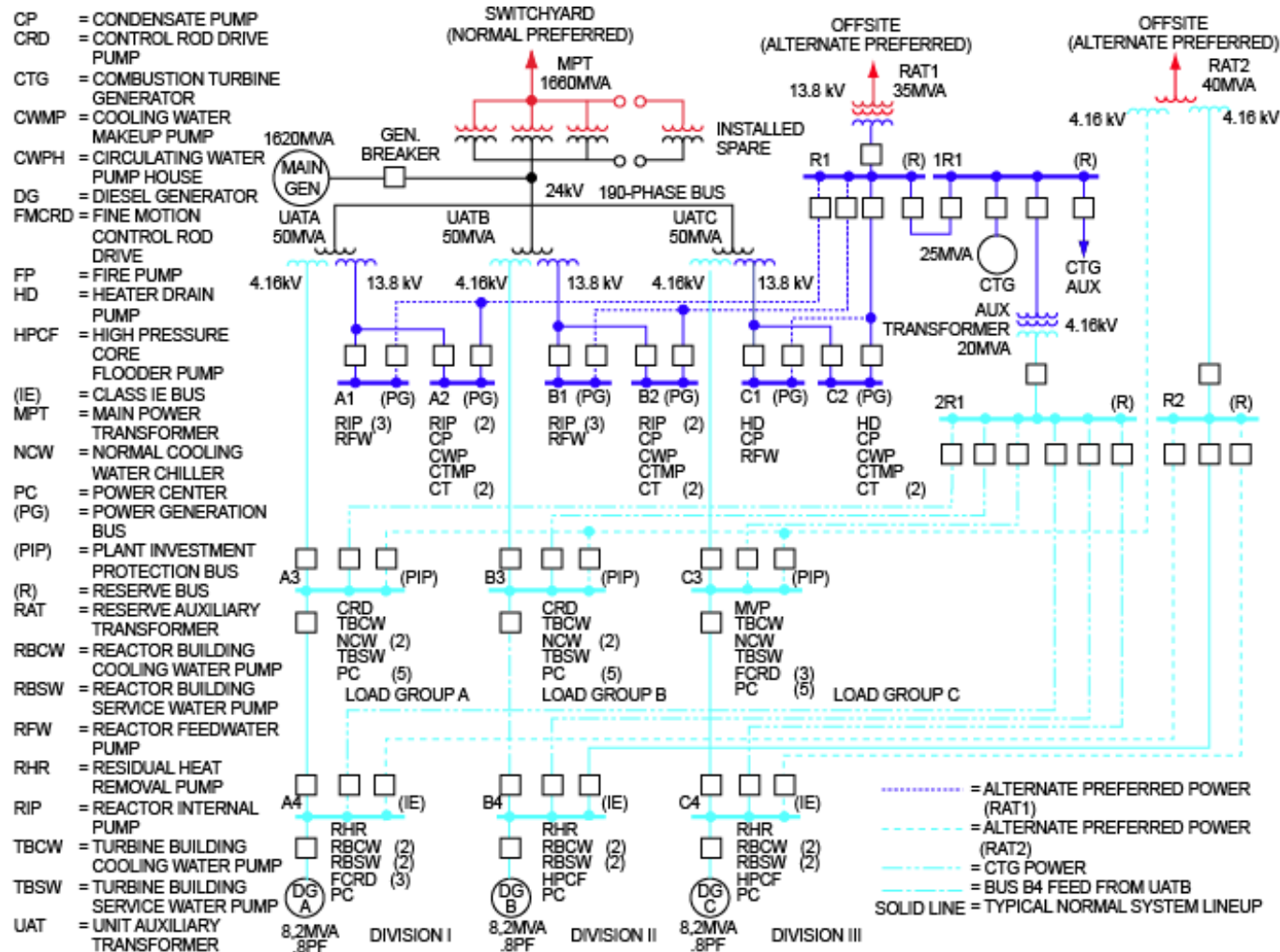
ABWR On-Site AC Power

- Three (3) Safety-related Diesel Generators (EDG)
 - One (1) per division
 - ~7 MWe each
- One Combustion Turbine Generator
 - ~20 MWe
 - For the purposes of Station BlackOut (SBO) rule (10 CFR 50.63, CTG is classified as an Alternate AC Power Supply
 - Automatically starts
 - » Connects to PIP Busses
 - » Can be connected to the Safety-Related Busses

Alternate AC Power Supply



ABWR Electrical Distribution



Standby Liquid Control (SLCS)

- **Purpose:** backup to Control Rods to bring & maintain core sub-criticality (Cold Shutdown)
- Two 100% Motor-driven Positive Displacement High Pressure Pumps
 - Injects liquid neutron poison into RPV
 - » Sodium Pentaborate (enriched is optional)
 - » Enters RPV via HPCF B
- Either Control Rods or SLCS ensure reactor shutdown at cold conditions
- Reactor Water CleanUp system (RWCU) automatically isolates

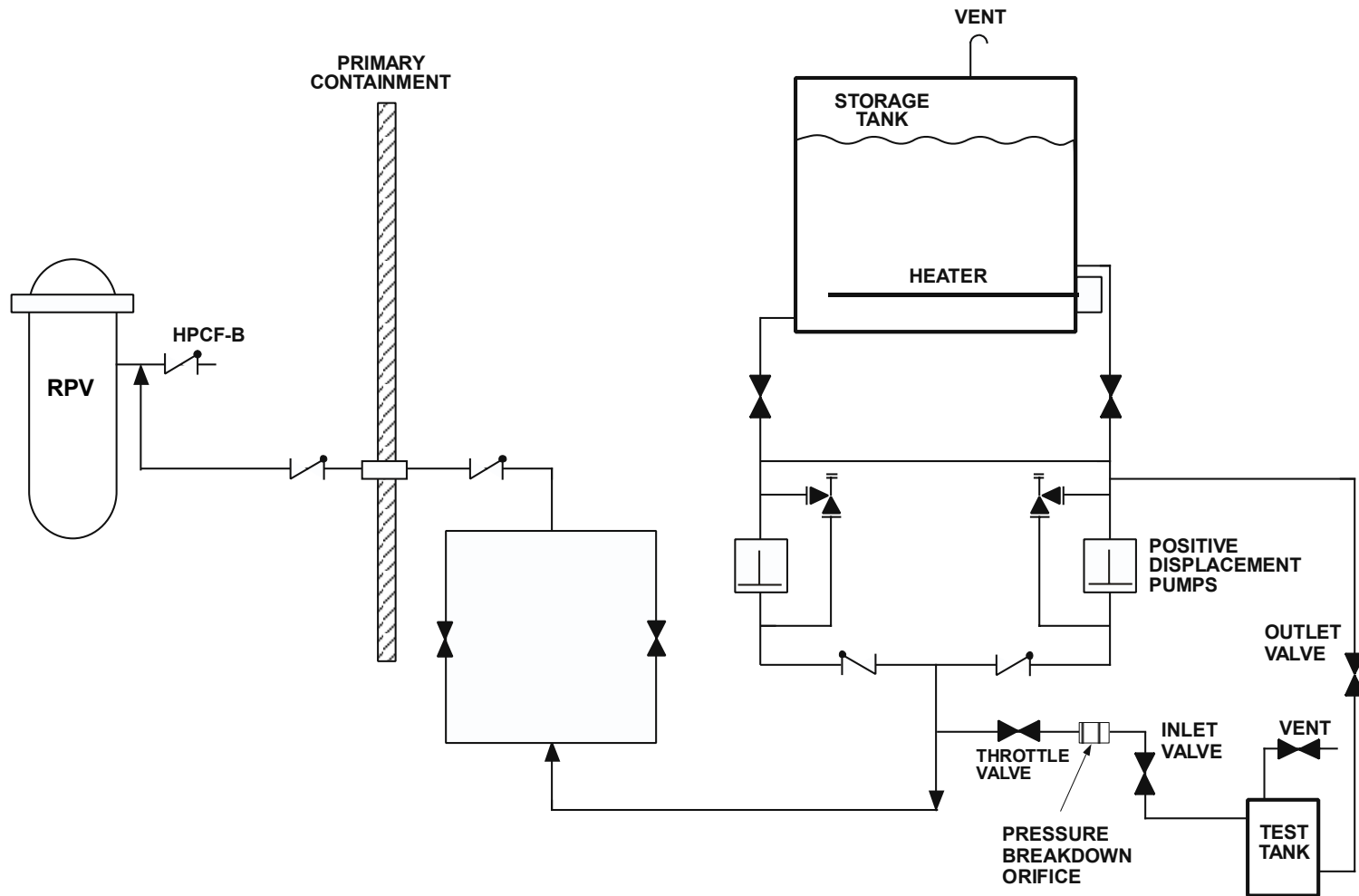
SLCS Reactivity Requirements

- To shutdown Rx with all Control Rods withdrawn.
- Must have enough negative reactivity to overcome:
 - Elimination of all steam Voids
 - Cool temperatures ($\sim 51.7^{\circ}\text{C}$; $\sim 125^{\circ}\text{F}$; water more dense & reduced Doppler effects)
 - Xenon free conditions
 - Dilution (to Residual Heat Removal (RHR) system)
 - Shutdown margin requirements

SLCS Initiations

- Manual from Main Control Room
 - Keylock switch for each division
- Automatic: Both divisions automatically initiate if Anticipated Transient Without Scram (ATWS) signal received
 - ATWS Signal: any of following conditions with 2 of 4 logic:
 - » High RPV Pressure (1125 psi); or low RPV water level (Level 2); or manual ARI/FMCRD run-in and
 - » Startup Range Neutron Monitor (SRNM) ATWS Permissive signal (i.e., 6% RTP or higher) for 3 minutes

ABWR SLCS

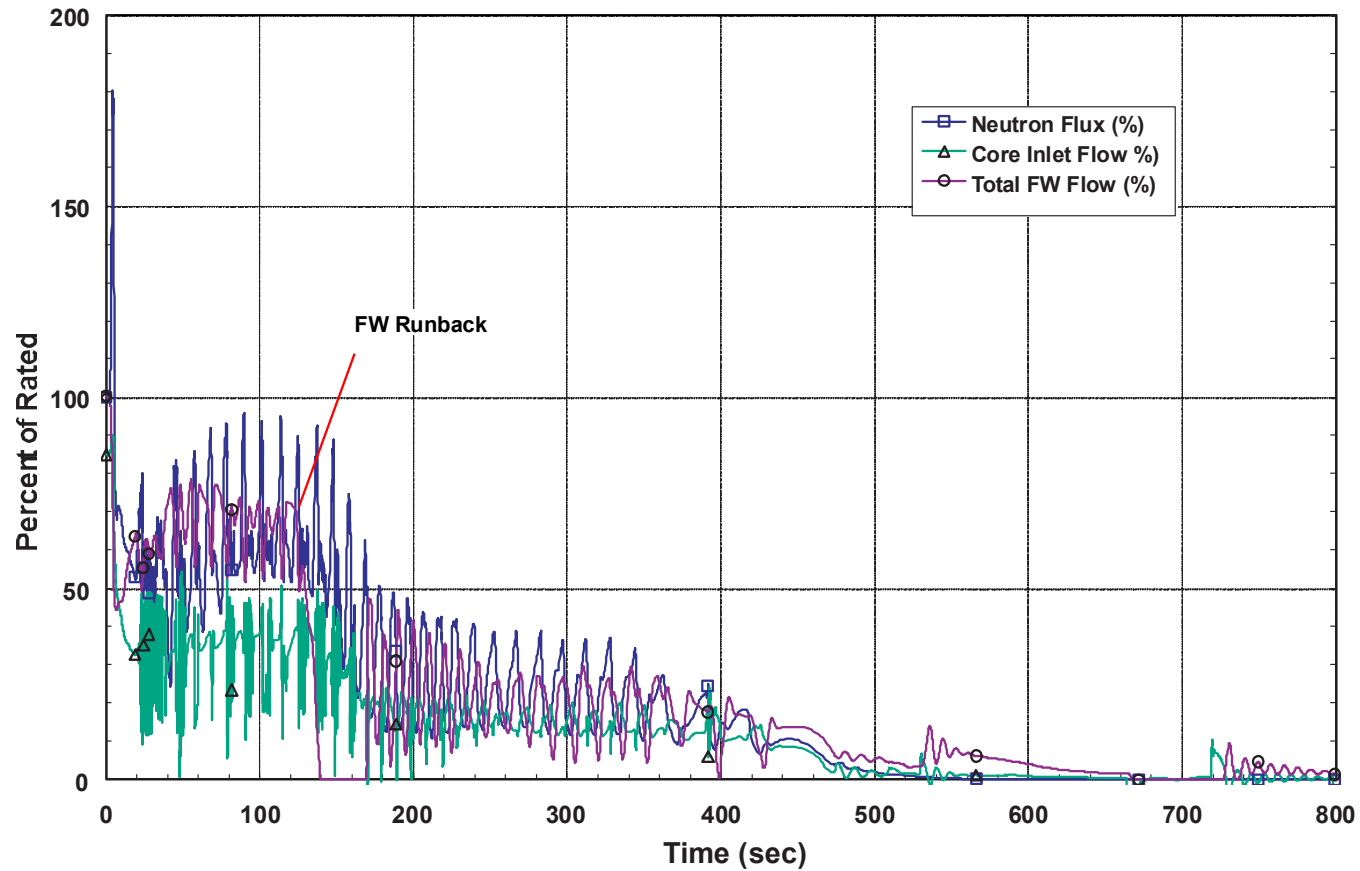


ABWR Safety Challenges Reduced

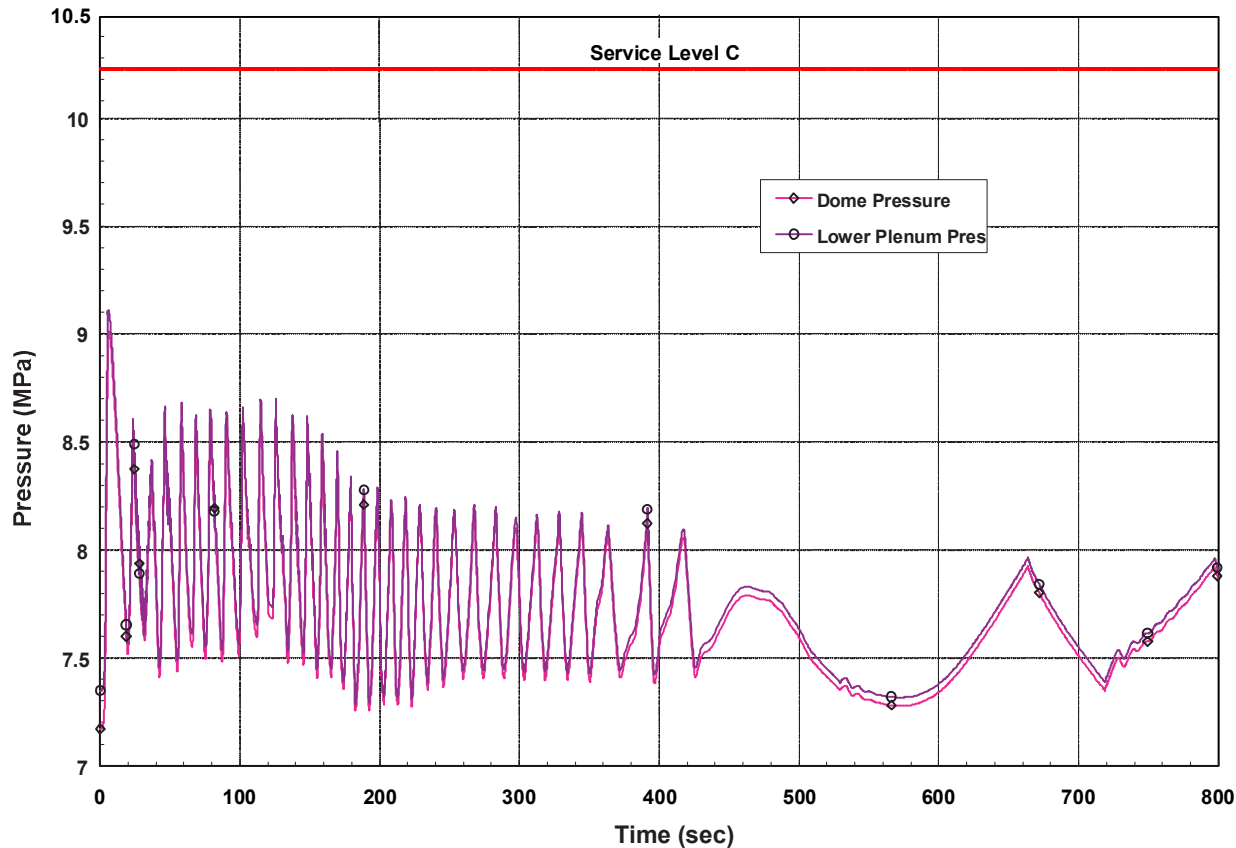
ATWS challenges reduced

- Prevention
 - Accumulator-driven Scram without Scram Discharge Volume
 - Alternate Rod Insertion (ARI)
 - » Diverse logic for Scram function
 - FMCRD electric run-in
- Automated mitigation
 - Recirculation pump trip (RPT)
 - » 6 on water level 2
 - » 4 on high reactor pressure or water level 3
 - » All on any scram or ARI
 - Feedwater runback
 - » High reactor pressure and SRNM ATWS permissive for 2 minutes
 - Boron injection

ATWS Mitigation – MSIV Closure



ATWS Mitigation – MSIV Closure



ATWS Mitigation – MSIV Closure

